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Decoding Xing-Ling codes

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Abstract — **This paper describes an efficient decoding method for a recent construction of good linear codes as well as an extension to the construction. Furthermore, asymptotic properties and list decoding of the codes are discussed.**

I. Xing-Ling codes

In [1] Xing and Ling describes a new construction of a class of linear codes (here referred to as Xing-Ling codes) which resulted in several improvements to Brouwer's table [2] of good linear codes.

A Xing-Ling code is a subfield subcode of a Reed-Solomon code over $\mathbb{F}_{q^2}$. While a Reed-Solomon code of dimension K is obtained by evaluating elements of $\mathbb{F}_{q^2}$ in all polynomials of degree at most $K-1$, a Xing-Ling code is obtained by evaluating certain elements of $\mathbb{F}_{q^2}$ in certain polynomials of degree at most $K-1$. The elements and polynomials are chosen in such a way that the result is a code over $\mathbb{F}_q$.

For any integer, K, let V_K denote the $\mathbb{F}_q$-vector space spanned by all monomials and monic binomials of degree less than K which only give values in $\mathbb{F}_q$ when evaluated in elements from $\mathbb{F}_{q^2}$.

We then have the following definition of Xing-Ling codes:

Definition 1 *Let $A \subseteq \mathbb{F}_q$ and $B \subseteq \mathbb{F}_{q^2} \setminus \mathbb{F}_q$ be given such that $\beta^q \notin B$ for all $\beta \in B$ and let K be given such that $V_K \neq V_{K-1}$. Then the following set is a Xing-Ling code:*

$$XL(A,B,K) := \{f(A,B) \mid f \in V_K\}$$

The main parameters of Xing-Ling codes are summarized in the following theorem:

Theorem 2 ([1], Theorem 2.5, 2.6, 2.9, and 2.10) *The code $XL(A,B,K)$ satisfies the following:*

1. *The code is a linear code over $\mathbb{F}_q$.*
2. *Let the number of elements of A and B be denoted by*
$$n_A := |A| \quad \text{and} \quad n_B := |B|.$$
The length of the code is then $n = n_A + n_B$ and if $K-1 = qr + s$ where $0 \leq s \leq q$ then the dimension is $k = (r(r+1))/2 + s + 1$.
3. *Let*
$$z := \begin{cases} \max\{2(r-1), r+s\} & \text{if } q \text{ is odd} \\ \max\{r-1, s\} & \text{if } q \text{ is even.} \end{cases} \quad (1)$$
Then the minimum distance, d, satisfies $d \geq d^*$ where
$$d^* := n - \left\lfloor \frac{K - 1 + \max\{\min\{z, n_A\}, 2n_A - \delta q\}}{2} \right\rfloor$$
with $\delta = 2$ for q odd and $\delta = 1$ for q even. Notice that for q odd the first term of the max*-expression is always largest since $n_A \leq q$.*

[1]This work was done at Department of Mathematics, DTU.

In the definition of Xing-Ling codes we have the constraints $n_A \leq q$ and $n_B \leq (q^2 - q)/2$ so the length of a Xing-Ling code is at most $q(q+1)/2$. However, the paper [3] describes how to extend the code with one position by evaluating in the point at infinity on the projective line. This gives a few improvements to Brouwer's table.

II. Decoding

Suppose that a word $r \in \mathbb{F}_q^n$ is received. The goal is to find the polynomial $\hat{f} \in V_K$ such that $\hat{f}$ corresponds to the Xing-Ling codeword closest to r. The paper describes an efficient method that calculates $\hat{f}$ if the corresponding codeword has distance less than half the designed minimum distance from the received word. The method is sketched below.

The word r is decomposed into two blocks, $r = (r_A, r_B)$ where r_A are the received values on the A-positions — the positions corresponding to the set A — and similarly r_B are the received values on the B-positions.

If $n_A \leq z$ (with z defined in Eqn. (1)) then it turns out that it suffices to decode the word (r_A, r_B, r_B) with a suitable Reed-Solomon code over $\mathbb{F}_{q^2}$.

If $n_A > z$ then this approach fails if too many errors occurred on the B-positions. In that case the word r_A is decoded with a Reed-Solomon code over $\mathbb{F}_q$. This results in an estimate, u, of $\hat{f}(\mathbb{F}_q)$. If q is even then decoding (u, r_B, r_B) with a Reed-Solomon code gives the result. If q is odd then the decoding is done with a so-called generalized Reed-Solomon m-code which is defined in the paper.

III. Asymptotic results

Let an infinite sequence of Xing-Ling codes be constructed for alphabet sizes tending to infinity such that for each alphabet size, q, we have $n_A = 0$ and $n_B = n = (q^2 - q)/2$ and such that the information rate (k/n) tends to a constant, κ.

For $q \to \infty$ it is then shown that the designed minimum distance, d^*, satisfies

$$d^*/n \to 1 - \sqrt{\kappa}$$

and that a fraction of errors, $t/n \to \tau$, can be efficiently list decoded whenever

$$\tau < 1 - \sqrt{\sqrt{\kappa}}.$$

References

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